CRATER EJECTA MORPHOLOGY AND THE PRESENCE OF WATER ON MARS; P. H. Schultz, Brown University, Department of Geological Sciences, Providence, Rhode Island 02912 B1720314

*Introduction:* Various approaches have been used to establish the presence of buried ice or water on Mars. A popular and frequently referenced diagnosic indicator has been the multi-lobed or rampart-bordered martian ejecta facies (1,2,3 among others). The implicit premise has been that fluidized ejecta facies indicates the presence of water; in fact, fluidized ejecta only indicate fluid-like emplacement. Laboratory experiments (4,5) have shown that rampart-bordered ejecta facies and ejecta flow lobes can develop without the presence of water. These results do not disprove the notion that subsurface water/ice exists but reveal the non-uniqueness in interpretations owing to a variety of controlling variables. The purpose of this contribution is to review the possible effects of projectile, target, and environment on the cratering process.

*Atmospheric Effects:* Laboratory experiments performed at the NASA-Ames Vertical Gun Range (AVGR) have documented the effects of an atmosphere on ejecta emplacement at small scales. For vertical impacts into compacted pumice, a systematic change in ejecta morphologies is observed with increasing atmospheric pressure (4,5): vacuum-like ($P_0$ < 0.05 $P_0$); contiguous rampart (0.1-0.3 $P_0$); multiple flow lobe (0.3-0.6 $P_0$); and radially scoured (0.7-1.0 $P_0$). These changes are accompanied by an increasingly distorted ejecta curtain and the development of a basal ejecta flow.

Further studies reveal the effects of atmospheric density impact velocity, and *in-situ* ejecta size. Reduced atmospheric density (He) still results in rampart-bordered ejecta facies in the appropriate pressure range (0.1-0.3 $P_0$) without significant distortion of the ejecta curtain. Impact velocity (from 0.03 km/s to 6.5 km/s) has little effect on ejecta morphology; therefore, ejecta curtain modification and the distinctive ejecta patterns reflect late-stage processes, decoupled from early-time impact velocity effects. An important variable, however, is the average *in-situ* grain size in the target. A shift in the modal grain size from 50 $\mu$ to 100$\mu$ also changes the onset of characteristic ejecta patterns to larger atmospheric pressures. A modest amount of fine-grained material (20% pumice) with coarser grained No. 24 sand, however, results in rampart-bordered ejecta facies at 1 $P_0$.

This brief summary indicates that Mars-like ejecta facies can be produced in the laboratory without the presence of water and principally depends on atmospheric pressure and ejecta size. The dynamic process responsible for the ejecta patterns has been revealed through stereo-photography and 1/4-space experiments wherein airflow patterns are revealed by splitting the evolving ejecta curtain in half. As summarized elsewhere (5,6), the outward movement of the wall of ejecta creates a partial vacuum within the crater cavity. At late-stages, this pressure difference results in a toroidal airflow that pursues the ejecta curtain. With increased atmospheric pressure, the relatively simple toroidal circulation breaks into tongues of air-ejecta. The process can be successfully scaled to much broader scales if the Froude number similitude is preserved and the Reynolds number is high enough (6).

Atmospheric pressure appears to establish the toroidal winds; air drag establishes limits on the size of ejecta that can be entrained. The latter effect requires that the combination of ejecta size, ejecta velocity, and drag coefficient must be properly simulated between the laboratory and martian conditions (8). If an impact-generated airflow is established but the ejection velocity is too low or ejecta size is too large. then ejecta emplacement will not be modified significantly. Such considerations indicate that at present atmospheric conditions, martian craters 5 km in diameter with a sufficient fraction (20%) of ejecta smaller than a few centimeters should result in craters with contiguous ramparts. Small craters do not result in sufficiently high ejecta velocities nor excavate (generate) sufficiently fine-grained ejecta. Larger craters or impacts into finer grained substrates will result in multi-lobed or even radial facies. As crater size increases, however, the effects of atmosphere scale height and secondary cratering reduce the role of the atmosphere (6).

*Effects of Volatiles:* The possible effect of high water content on ejecta emplacement has been studied in the laboratory both directly (9) and indirectly (10). A difficulty in directly equating the presence of water with fluid-like ejecta flow is the fate of ballistic water in the martian atmosphere. The low velocities (cm/s) for near-rim ejecta in the laboratory preserve the splosh-like behavior, whereas the high-velocities (50 m/s) for ejecta around a 5 km-diameter martian crater result in aerodynamic dispersal and atomization. During ballistic ejection, the distinction between drag-decelerated ejecta and drag-decelerated atomized water becomes less apparent. During emplacement, the inner near-rim lobe may reveal the effects of decreased viscosity due to the presence of water, whereas the outer facies records a more complex behavior reflecting atmospheric interactions and air entrainment (8,11).

Recent laboratory experiments have explored the possible effects of impact-induced vaporization by using powdered dry-ice on the surface at the point of impact (7,12). High-frame-rate photography (8,000-35,000 fps) reveals enhanced vaporization and ionization in the presence of an atmosphere or for oblique impacts. Early-time (< 10% completion) modification of the ejecta curtain does not persist to late time, and contiguous ramparts are produced. This is primarily because impact-induced vapor is jetted vertically and expands. The expanding vapor cloud scours the pre-impact surface well in advance of the ejecta plume. Although decoupled from the plume, the presence of the dry-ice resulted in a decreased ejection angle during the early stages of crater growth. Burial of the dry-ice has little effect on ejecta emplacement and does not result in a two component curtain as suggested in (13).

*Discussion:* For a given size crater between 5 and 20 km in diameter, a relatively contiguous rampart-bordered ejecta facies is believed to reflect the presence of relatively coarse ejecta sizes. Multiple rampart-bordered ejecta lobes around craters of the same given size reflect an increased fraction of smaller ejecta. Strong radial grooves indicate an even greater contribution by smaller ejecta. This sequence from contiguous rampart to multiple rampart to radial grooves reflects the increased entrainment of ejecta in the recovery airflow pattern created by the advancing ejecta curtain. The different emplacement styles correspond to a factor of 10-20 in ejecta size. Transitions from one ejecta emplacement style to another also can be produced by different atmospheric pressure, thereby perhaps accounting for craters of identical size but different ejecta morphologies only 50 km apart on the same geologic unit. It is important to note that the possible range in atmospheric pressures due to time variations (factor of 5) or to elevation (factor of 7) is small compared with the potential range range in target-controlled ejecta sizes. Because the effect of such variations is reflected in shifts in ejecta emplacement styles with crater size, a given region still may exhibit the same range in ejecta morphologies. Ejecta size is controlled by *in-situ* particle size and impact-induced comminution. The former control reflects local geologic history; the latter reflects processes including effects of impact velocity, total impact energy, and target-entrapped volatiles.

This discussion suggests that contradictions in interpreting martian crater ejecta morphologies reflect oversimplifying the process as a singular consequence of buried water. It seems entirely possible that most ejecta facies could be produced without the presence of liquid water. However, the combination of extraordinary ejecta fluidity, absence of secondaries, and high ejection angles all would point to the combined effects of atmosphere and fluid-rich substrates (11). Moreover, recent experiments revealing the broad scour zone associated with rapid vapor expansion may account for numerous craters in the circum-polar regions with subtle radial grooving extending 10 crater radii away with faint distal ramparts. Thus certain crater ejecta morphologies may yet provide fundamental clues for the presence of unbound water.

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